



RESEARCH ARTICLE

FINITE ELEMENT METHOD BASED STRUCTURAL ANALYSIS OF QUADCOPTER UAV CHASSIS PRODUCED WITH 3D PRINTER

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ABSTRACT

In this study, the static analysis and manufacturing of a quadcopter type small unmanned aerial vehicle (UAV) design compatible with landing platforms was performed by using the finite element method. In static analysis, the weight of the quadcopter body is considered as the load and the base is fixed. Each part of the quadcopter used in the Finite Element Analysis (FEA) is manufactured with Acrylonitrile Butadiene Styrene (ABS) and Polyactic Acid (PLA) materials with a thickness of 0.05 mm with i3 prusa printer. As a result of the structural analysis, the stress produced in the quadcopter chassis produced from ABS material was 0,053 MPa and the stress on the quadcopter frame produced from PLA material was calculated as 0,065 MPa. In addition, the deformation in the quadcopter frame produced from ABS material was 0,014 mm, while the quadcopter frame produced from PLA material was 0,010 mm.

Keywords: *3D manufacturing, FDM, Quadcopter UAV, Finite element method*

1. INTRODUCTION

Manufacturing methods are developing rapidly with technology. Traditional manufacturing methods are generally based on the principle of material removal from the workpiece [1,2]. Unlike traditional manufacturing methods, in additive manufacturing technologies, which have become more common in recent years, the basic principle is to add layers to the material, not to reduce parts from the material [1-5]. In contrast to casting and injection molding method, there is no initial investment and maintenance cost in additive manufacturing technology [6,7].

In the last 10 years, the application area of 3D manufacturing have increased in the production of final products or visual prototypes in many different fields from dental implant production to the construction of engine parts. In recent years, the use of 3D printers has increased considerably due to the reduced costs and widespread use. The use of these devices is not limited to industrial facilities

and research institutes. The use of 3D printers has reached the individual user. Desktop 3D printers are widely used in homes or hobby workshops [7,8]. In recent researches realized in 2018, it was stated that ten different methods have been developed for 3D manufacturing technologies. These methods are Fused Deposition modeling (FDM), stereolithography (SLA), Digital Light Processing (DLP), Selective Laser Sintering (SLS), Direct Metal Laser Sintering (DMLS), Selective Laser Melting (SLM), Electron Beam Melting (EBM), Material Jetting (MJ), Drop on Demand (DOD) and Binder Jetting (BJ) [9]. In addition FDM method has a feasibility of desktop usage in recent years.

In the FDM method, thermoplastic or thermoplastic derivative materials are used as building materials. In this method, ABS, PLA and rarely composite based filaments are used [5-7]. ABS (Acrylonitrile Butadiene Styrene) is an oil-based polymer. It is an inexpensive material for low cost prototyping. However, it spreads toxic gases after burning with high temperature. Therefore, it should not be in contact with food [8]. PLA (Polylactic Acid) material is obtained from renewable resources. PLA material has a medium cost price and is an excellent 3D printer material [8]. PLA material is made from organic materials like renewable, corn starch or sugar cane. PLA material is often used to make food packaging, medical devices and implants [10]. FEA which is significant method used in structural analysis of engineering designs [12]. In recent years, FEA was used to analyze the design of quadcopter chasis with PLA and ABS materials.

Today, there is a significant increase in applications related to the aerial surveillance system [13]. These systems are developed by companies that working with unmanned vehicles [14]. This study focused on structural analysis of a quadcopter chasis that is main simple component of aerial surveillance [15].

2. EXPERIMENTAL STUDIES

2.1. 3D Modeling and Analysis

In this study, the 3D model of a quadcopter unmanned aerial vehicle that is shown in Figure 1a. was created using the SolidWorks-2018. Computer-assisted analyzes were performed using AnsysWorkbench software. 3D CAD models were transfered into AnsysWorkbench software to prepare the finite element model. Load conditions, boundary conditions and material models are defined in AnsysWorkbench. In Figure 1b, the quadcopter chasis produced with PLA material by using FDM method is shown.



Figure 1. a) 3D model of quadcopter chasis b) 3D printed quadcopter chasis produced from PLA.

Quadcopter has 6 degree of freedom and its dynamic model has 6 equations of movement. Dynamic model of the quadcopter includes virtual inputs composed by angular velocities of rotors. The angular velocities (ω_i) of the rotors are the real input variables of the quadcopter UAV. However, at the mathematical model is used virtual inputs that consisting of angular velocities. Virtual inputs are given in equations 1-4.

$$u_1 = (\omega_1^2 + \omega_2^2 + \omega_3^2 + \omega_4^2) \quad (1)$$

$$u_2 = (\omega_1^2 - \omega_3^2) \quad (2)$$

$$u_3 = (\omega_2^2 - \omega_4^2) \quad (3)$$

$$u_4 = (\omega_1^2 - \omega_2^2 + \omega_3^2 - \omega_4^2) \quad (4)$$

In equations 1-4, u_1 is the thrust force acting on the body of the quadcopter, u_2 is the force that generates the rolling torque, u_3 is the force that generates pitching torque, u_4 is the force that generates the turning torque. Dynamic model quadcopter was shown in equations 5-10. In this equations, d (drag) is impact factor. L is distance from the propellers to the center of the quadcopter, m is total mass of quadcopter. I_x I_y I_z are moment of inertia on basic axes.

$$\ddot{x} = (\cos\psi\sin\theta\cos\varphi + \sin\psi\sin\varphi) \frac{u_1}{m} \quad (5)$$

$$\ddot{y} = (\cos\psi\sin\theta\sin\varphi - \sin\psi\cos\varphi) \frac{u_1}{m} \quad (6)$$

$$\ddot{z} = -g + \cos\theta\cos\varphi \frac{u_1}{m} \quad (7)$$

$$\ddot{\varphi} = \dot{\theta}\dot{\psi} \left(\frac{I_y - I_z}{I_x} \right) + \frac{L}{I_x} u_2 \quad (8)$$

$$\ddot{\theta} = \dot{\varphi}\dot{\psi} \left(\frac{I_z - I_x}{I_y} \right) + \frac{L}{I_y} u_3 \quad (9)$$

$$\ddot{\psi} = \dot{\theta}\dot{\varphi} \left(\frac{I_x - I_y}{I_z} \right) + \frac{d}{I_z} u_4 \quad (10)$$

In Table 1, was given parameters and values of parameters that used in mathematical model design of quadcopters.

Table 1. Value of parameters used in the mathematical model of quadcopter.

| Parameter | Value(PLA) | Value(ABS) |
|-----------|-----------------------|-----------------------|
| g | 9,81 m/s ² | 9,81 m/s ² |
| m | 0.81 kg | 0.65 kg |
| L | 0.25 m | 0.25 m |

| | | |
|-------|--------------------------|--------------------------|
| I_x | 0.0132 kg m ² | 0.0104 kg m ² |
| I_y | 0.0132 kg m ² | 0.0104 kg m ² |
| I_z | 0.0257 kg m ² | 0.0205 kg m ² |

2.2. Loading and Boundary Conditions

Meshing was performed by using a hex-dominant finite element type for FEA as shown in Figure 2. The FEA model has 323719 nodes and 82601 elements. Element size was chosen to 5 mm. Total weight of the quadcopter have considered as load. Quadcopter was fixed on the base surface as shown in Figure 3.

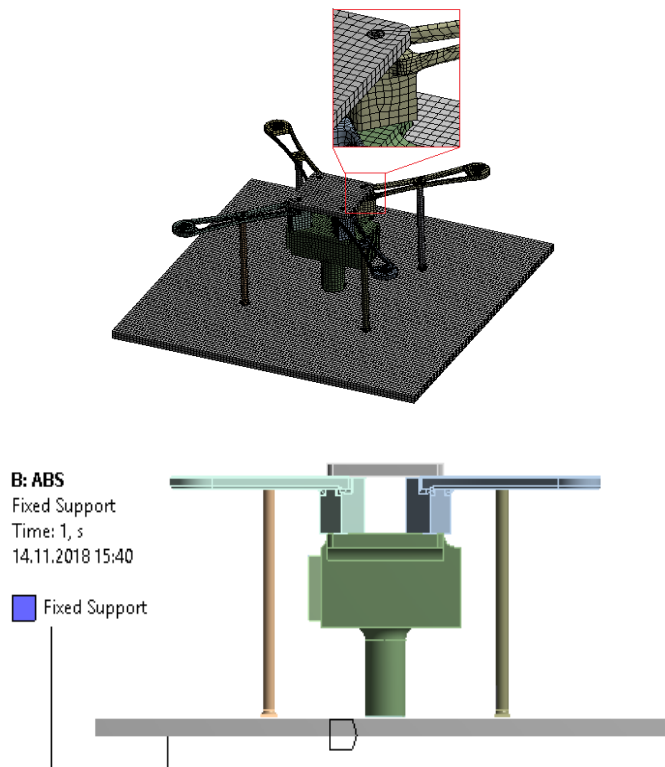


Figure 3. Loading and boundary conditions.

Mechanical properties of ABS and PLA plastic materials are given in Table 2. These values was taken from library of AnsysWorkbench. Soil was selected from Ansys Workbench material library for floor [8]. Convergence analysis is shown in Figure 4 [9].

Table 2. Mechanical properties of materials used in FEA.

| Parameters | ABS [10] | PLA [11] |
|------------------------------|----------|----------|
| Density (kg/m ³) | 1020 | 1252 |
| Elastic Moduls (MPa) | 2230 | 3500 |
| Yield Strength (MPa) | 33 | 70 |
| Poisson Ratio | 0,34 | 0,36 |

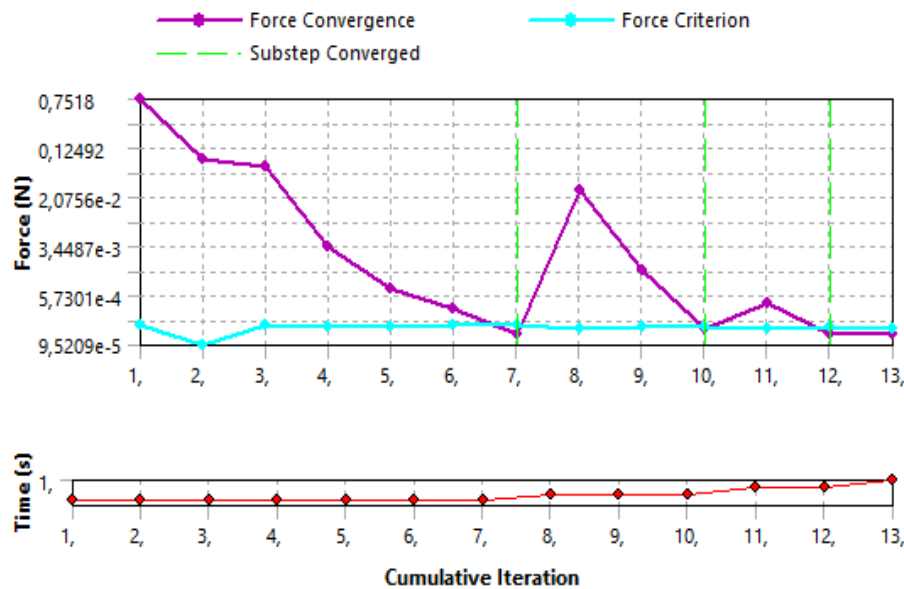


Figure 4. Convergence analysis.

3. EXPERIMENTAL RESULTS

Finite element analyzes were performed after the loading and boundary conditions were defined. When quadcopters land on to soil ground, stress that was shown in Figure 5 was consisted with impact of its weight. Deformation that consisted with impact of its weight was shown in Figure 6. In Figure 5 and Figure 6. As a result of the structural analysis, the stress occurred in the quadcopter chassis designed with ABS material was 0,053 MPa, whereas design with PLA material was calculated as 0,065 MPa. In addition, the deformation in the quadcopter frame designed with ABS material was 0,014 mm, while the quadcopter frame desigend with PLA material was 0,010 mm. In Table 3, stress and deformation values are given.

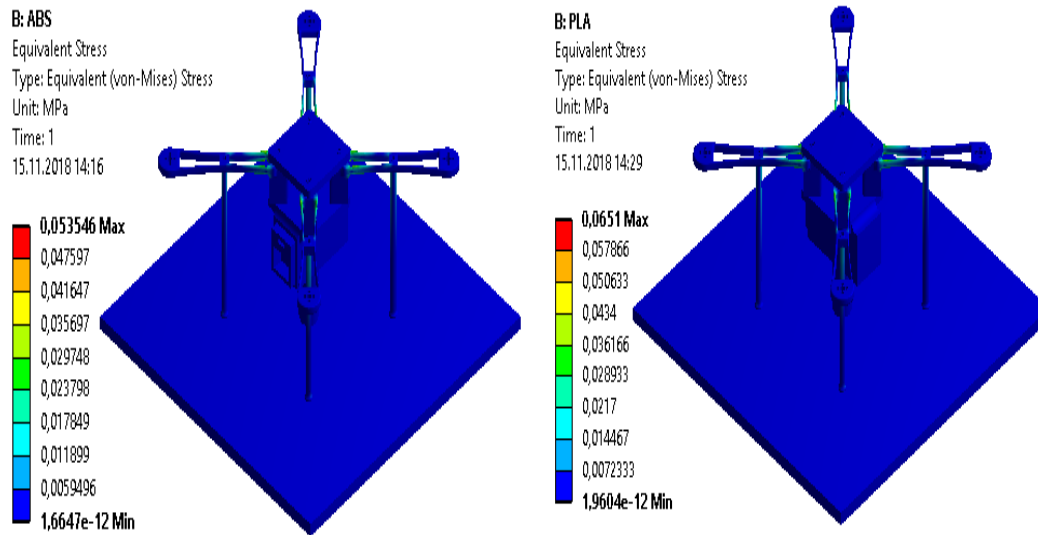


Figure 5. Tensile values, a) produce of ABS material, b) produce of PLA material.

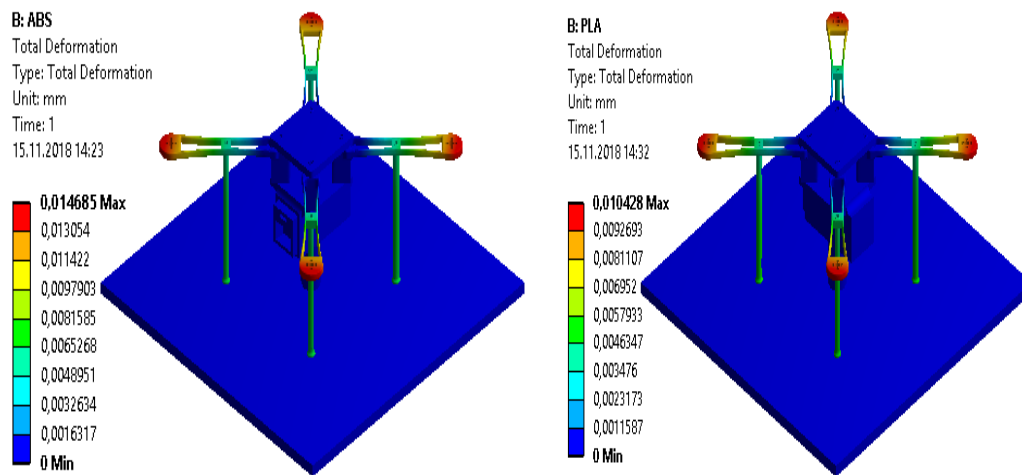


Figure 6. Deformations values a) ABS and b) PLA.

Table 3. Deformation and stress values for quadcopter chasis.

| Material | Stress (MPa) | Deformation (mm) |
|----------|--------------|------------------|
| ABS | 0,053 | 0,014 |
| PLA | 0,065 | 0,010 |

4. CONCLUSION

PLA material has a high modulus of elasticity and a high yield strength. Therefore, when contacting on the ground with a load of quadcopters own weight, strains occur at the contact points of the arms. These stresses are higher stresses according to ABS material. The modulus of elasticity is inversely proportional to elastic deformation as is seen in equation 11 and equation 12. The modulus of elasticity is the resistance of the material to elastic deformation. Therefore, PLA that have high modulus of elasticity is expected to constitute lower deformation.

$$E = \frac{\sigma}{\varepsilon} \quad (11)$$

$$\sigma = E \cdot \varepsilon \quad (12)$$

The stresses (0,053 MPa ve 0,065 MPa) formed in the quadcopters designed with materials ABS and PLA are very low ((ABS, $\sigma_{ak} = 33 \text{ MPa}$), (PLA, $\sigma_{ak} = 70 \text{ MPa}$)). Since the stresses that occur in analysis did not exceed yield strength of material, any damage wasn't comprise in both designs. However, PLA material is economical, it does not create toxic materials during manufacturing, it prints without using table heating during printing and creates lower deformation during printing. Therefore, it has been determined that it is more appropriate to use filament obtained from PLA material.

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